UDC 311.2.330.3;33.339.7

ECONOMICAL-MATHEMATICAL MODEL OF CHANGES IN SPATIAL MIX OF PRIVATE AGRICULTURAL FARMS IN POLAND

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Оцінено сучасний стан аграрного виробництва у Польщі порівняно зі світовими та європейськими досягненнями. Виконано аналіз факторів, що впливають на зміну просторових зрушень розмірів приватних фермерських господарств. Технологічна модель, запропонована Квашніцьким для дослідження та прогнозування процесів змін у співвідношенні глобального використання різних джерел енергії (1998), застосована до визначення змін просторових зрушень. Зміна відсоткової частки технології впродовж певного періоду часу визначається за формулою $f_i(t+1)=\frac{f_i(t)c_i}{\bar{c}(t)}$*. Тобто зміна залежить від частки відповідної технології у попередньому періоді* $f_i(t)$ *та рівня її конкурентоспроможності* c_i*, віднесених до середньої конкурентоспроможності, що обчислюється таким чином:* $\bar{c}(t)=\sum_{i=1}^{n} f_i(t)\,c_i(t)$*. Конкурентоспроможність тут інтерпретується як відносна міра корисності, що може бути отримана фермером унаслідок управління господарством цієї категорії.*

Динамічну економіко-математичну модель побудовано з використанням програмного забезпечення STELLA. Просторове моделювання зрушень охоплює період у 100 років: статистичні дані за 60 років та прогноз на наступні 40 років.

Зазначається, що чинники, які мали вплив на трансформацію в аграрній сфері Польщі в досліджуваному періоді, вийшли далеко за межі сільськогосподарської економіки. Значною мірою це обумовлюється макроекономічною ситуацією, соціальними проблемами, а також державною політикою.

Introduction. The model of changes in the spatial mix of agriculture depends on a variety of factors. It is undoubtedly firmly rooted in the historical perspective as the previous status determines to a large extent how the contemporary outlook is perceived. Changes in the spatial mix of farms are brought about by socio-economic transformations and – to a similar extent - by the state policy. The latter had a big impact on the agrarian mix of the Polish agriculture, both under the command-and-quota system as well as under the market economy. Under both systems, various state intervention tools were applied in the farming sector in Poland, directly contributing to the deformation of the agrarian mix. In the regional perspective, the spatial mix is additionally differentiated by fixed features of the natural environment. Nevertheless, the contemporary framework of the Polish agriculture is predominantly a result of socio-economic changes which have shaped its image to a much larger extent than natural conditions.

The agrarian mix, and the spatial mix of agriculture in particular, is of material significance as it directly determines farmers' economic status, while indirectly - their social status. It may bring about adverse cultural changes and a disappearance of rural tradition. It may also have an indirect, nonetheless material, impact on the condition of the natural environment.

Based on the comparison of international cases, a conclusion may be drawn that the Polish agriculture has significant resources of arable land. Its area was estimated at 18,9 million hectares for 2009. Among 27 EU member states, only France and Spain ranked higher in this category, whereas Germany, the United Kingdom, Romania, and Italy disclosed comparable figures. Polish agriculture has also a large production capacity, the fact confirmed by e.g. a high third position in the global rye production; seventh position in potato production, eighth position in sugar beet production, tenth position in cow milk production, and thirteenth position in culled meat production.

Poland accounts for 10% of grain production, 7,8% of culled meat production, and 8,3% of milk production for the entire EU.

Polish agriculture may be described as being of considerable significance to both the European Union as well as the entire world. However, since several decades, its markedly characteristic feature (and simultaneously its biggest drawback) is a sustained trend for excessive fragmentation, which prevents it from fully utilizing its production capacity. Publically available statistical data indicate that in 1950, half of the total number of 2,76 million private agricultural farms had the area of less than 5 hectares of arable land. The number of private farms in Poland dropped to 1,77 million against 2009 data, however, the figure remained very high against other EU-15 member states.

The share of small and very small farms (with the area less than or equal 5 hectares) in the total figure cited above, increased in Poland by more than 7% against 1950s. This resulted from increasingly marked polarization of the spatial mix of the Polish agriculture. As a result, a marked reduction in medium-sized farms (i.e. between 5 and 10 ha) was noted in the period in question, coupled by an increase in the number of the largest and the smallest farms. Statistical data indicates that the share of medium-sized farms dropped by as much as 13,3% over the last 60 years. As recently as in 1950s, these farms represented more than one-third of all private farms in Poland. At present, they account for slightly more than 22% of the total mix. This study strives to provide a mathematical depiction of changes in the spatial mix of the Polish agriculture. To facilitate this, relevant statistical data was collected, following which a dynamic model was developed and calibrated. The authors are convinced that if the model is developed further, it may be applied to diagnose the process of shaping the spatial mix of the Polish agriculture in a more thorough manner and to anticipate changes in the mix as a result of current agricultural policy.

Results and discussion. The research method used in the study consists in the technological substitution model discussed by Kwa[nicki (1998). Mathematical presentation of a substitution of competing technologies depicts a change in the percentage share of a single technology over time as a bell-shaped curve. It can be divided into the preliminary stage, the relatively fast diffusion stage, the maturity stage, and the decline stage, which is represented by the replacement of a given technology with other more competitive technologies (more affordable technologies and/or technologies marked by better technical parameters).

Change in the percentage share of technology *i* over time is expressed by way of the following formula:

$$f_i(t+1) = \frac{f_i(t) c_i}{\overline{c}(t)}$$

Thus, the change depends on the percentage share of technology *i* in the preceding period and on its competitiveness level (c_i) against average competitiveness which is calculated in the following manner:

$$\overline{c}(t) = \sum_{i=1}^{n} f_i(t)\, c_i(t)$$

The model was applied by Kwa[nicki to facilitate the study and forecasts of the change process for global shares of various energy sources. The model provided an explanation as to the manner wood considered an energy source marked by a low competitiveness level was gradually replaced with coal, whereas coal with petroleum, gas, and nuclear energy as of the turn of the 19th century. The model provides a high-level explanation of substitution processes. To depict an evolution of the framework of applicable technologies, in principle only start share values and competitiveness level values are required to be substituted in the model.

Upon the study of the model discussed by Kwa[nicki, it was concluded that a similar concept could serve as a tool to facilitate a study of the change in the spatial mix of private agricultural farms in Poland since a higher share of very small and very big agricultural farms against medium-sized farms is determined by a higher competitiveness level of the former here as well. In this case, however, competitiveness should be interpreted as a relative measure of benefits obtained by the farmer as a result of running a farm in a given size category.

Data required for developing the model has been collected from two secondary sources. Spatial mix of private farms between 1950 and 2000 is discussed by Kapusta (2003). Further evolution of the mix (in years 2000-2009) can be tracked in an online database containing local data published by the Central Statistical Office. Data provided by these two sources has not been collected in the same manner. Their correspondence made it possible, however, to develop a coherent database which depicts change in the spatial mix of the Polish agriculture for 5 size categories of private agricultural farms between 1950-2009 (тable 1).

Preliminary study of data contained in table 1 allows to conclude that changes in the spatial mix of the Polish agriculture were nonlinear in nature and subject to fluctuations, which is confirmed by graphic depiction presented in fig. 1 developed using data quoted above.

Table 1: Change in the number and mix of private agricultural farms in Poland.

Years	Total number (In million)	Mix (%)				
		1-2ha	2-5ha	5-10ha	10-15ha	Above15ha
1950	2,762	15	35,9	35,4	8,9	4,8
1960	2,937	17,8	37,2	31,9	9,7	3,4
1970	2,737	17,3	35,3	32,4	10,8	4,2
1980	2,390	18,7	37	30	10	4,3
1987	2,235	18,7	34,8	29,3	11,2	6
1990	2,138	17,7	35,1	29,8	11,3	6,1
1996	2,041	22,6	32,7	25,5	10,6	8,5
2000	1,881	23,8	32,6	23,8	9,9	9,9
2001	1,882	22,8	33,8	24,3	9,7	9,4
2002	1,952	26,5	32,3	21,9	9,4	10,1
2003	1,850	25,8	33	22,1	9,3	9,9
2004	1,852	26,1	32,1	21,8	9,6	10,5
2005	1,782	25,1	32,8	21,8	9,4	10,9
2006	1,806	23,2	33,8	23	9,4	10,6
2007	1,804	23,4	34	22,2	9,2	11,2
2008	1,806	23,7	33,4	22,8	9,1	11
2009	1,766	23,4	33,8	22,1	9,4	11,3

Source: Authors' own study based on Kapusta (2003) and local database published by the Central Statistical Office.

The dynamic model of the spatial mix in the Polish agriculture has been developed using STELLA software. Interactions with the software relate to two areas, i.e. a flow chart and specific differential equations. The flowchart is used to define types of impacts between relevant model components. In the course of its development, relevant data is fed into the software. The process is automated whereby equations which record the model are developed successively upon the provision of subsequent pieces of information about its structure, which is encoded in the flowchart. Flowcharts are created by selecting a relevant symbol (rectangle, faucet, circle, or arrow) and placing it on the working screen. These tasks are conveyed by equations generated by the software. Model components (resources, streams, and supplementary variables) are associated according to the researcher's concept. Equations (a descriptive component) and flowcharts (a graphic component) contain necessary minimum information about the model. They are sufficient to recreate and test practically any dynamic model.

The STELLA-generated flowchart uses the rectangle symbol to depict cumulative variables. The faucet symbol represents streams. The circle symbol represents any supplementary variables which are used to define model parameters and supplementary interdependencies which define the target system. The arrow symbol is used to mark interdependencies between relevant model components (see fig. 2).

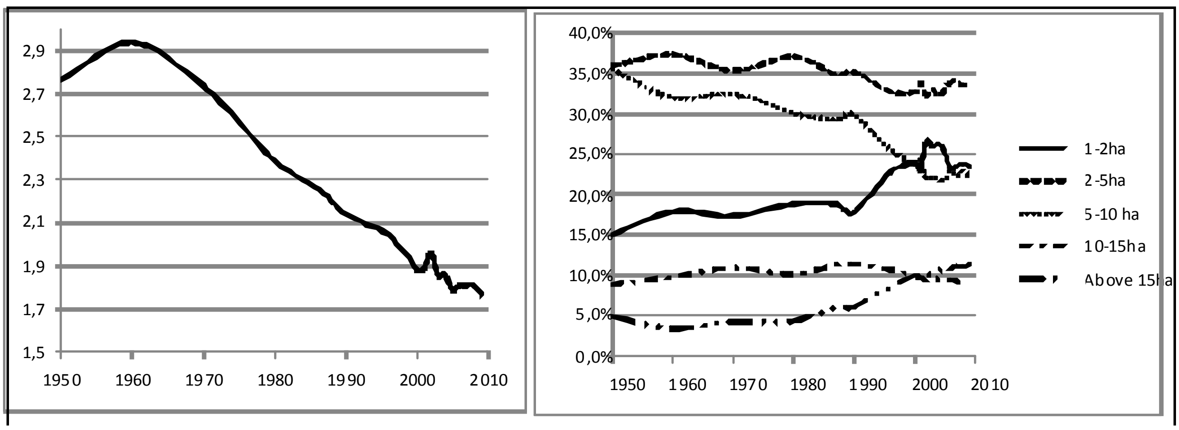

Fig. 1. Change in the number (in millions) and mix (%) of private agricultural farms in Poland

Source: Authors' own study.

Three different categories of variables may be distinguished in dynamic models, i.e. resources, streams, and supplementary variables. The feature of resources which are also referred to as cumulative variables is the fact that they depict a cumulative state of certain economic values at a given moment. In case of the model in question, percentage share of farms which belong to a given size category represent resources. A resource is always linked to at least one stream as the goal of streams is to supply or reduce resources. In terms of the model in question, streams stand for a change in the percentage share of farms which belong to a given size category. Streams and resources are inter-related even though they are completely different in nature as the feature of streams is their specific temporal perspective. Streams are identified as a flow of a specific number of an economic value over a given time noted by a relevant entity or economy (Milewski, Kwiatkowski 2004). It would not be possible to outline a system composed of a single or more resources if no reference was made to stream variables. Streams account for changes taking place in the system, are subject to balancing processes, and are decision-making in nature. In system dynamics models, streams which account for a pace of change applicable to resources are derivative equivalents.

Five resources may be distinguished in the model flowchart. They are as follows: percentage shares of relevant size categories of private agricultural farms in the total number of farms (*UG od 1 do 2 ha* – percentage share of farms between 1 and 2 ha, *UG od 2 do 5 ha* – percentage share of farms between 2 and 5 ha, *UG od 5 do 10 ha* – percentage share of farms between 5 and 10 ha, *UG od 10 do 15 ha* – percentage share of farms between 10 and 15 ha, and *UG pow 15 ha* – percentage share of farms exceeding 15 ha). Moreover, five two-way streams may be noted (df1, df2, df3, df4, df5). They represent increases or decreases in the share of relevant size categories of agricultural farms over time whereas supplementary variables represent competitiveness levels of relevant size categories (c1, c2, c3, c4, c5) and the average competitiveness of the entire system depicted in the model (c[r). Additionally, five supplementary variables are used whose aim is to ensure a straightforward estimation of average competitiveness of the system depicted in the model (f1c1, f2c2, f3c3, f4c4, f5c5). The following set of equations which define the model has been generated for the flowchart (see fig. 2):

UG od 1 do 2ha(t) = UG od 1 do 2ha(t - dt) + (df1) * dt

INIT UG od 1 do 2ha = 0,150

INFLOWS: df1 = (UG od 1 do 2ha*c1/c[r) - UG od 1 do 2ha

UG od 2 do 5ha(t) = UG od 2 do 5ha(t - dt) + (df2) * dt

INIT UG od 2 do 5ha = 0,359

INFLOWS: df2 = (UG od 2 do 5ha*c2/c[r) - UG od 2 do 5ha

UG od 5 do 10ha(t) = UG od 5 do 10ha(t - dt) + (df3) * dt

INIT UG od 5 do 10ha = 0,354

INFLOWS: df3 = (UG od 5 do 10ha*c3/c[r) - UG od 5 do 10ha

UG od 10 do 15ha(t) = UG od 10 do 15ha(t - dt) + (df4) * dt

INIT UG od 10 do 15ha = 0,089

INFLOWS: df4 = (UG od 10 do 15ha*c4/c[r) - UG od 10 do 15ha

UG pow 15ha(t) = UG pow 15ha(t - dt) + (df5) * dt

INIT UG pow 15ha = 0,048

INFLOWS: df5 = (UG pow 15ha*c5/c[r) - UG pow 15ha

c1 = 0,9932

c2 = 0,9860

c3 = 0,9794

c4 = 0,9890

c5 = 1,0000

c[r = f1c1 + f2c2 + f3c3 + f4c4 + f5c5

f1c1 = UG od 1 do 2ha*c1

f2c2 = UG od 2 do 5ha*c2

f3c3 = UG od 5 do 10ha*c3

f4c4 = UG od 10 do 15ha*c4

f5c5 = UG pow 15ha*c5

Model calibration is an important task when conducting system simulations. While calibrating, parameter values are set so that the system reflects the reality at hand to the possible approximation. A simplified calibration of the model presented above was conducted in the following manner: start values of percentage shares in subsequent size categories of farms were assumed based on 1950 data concerning a relevant mix (fig. 2). These values were expressed as a set of equations which define the model (e.g. „INIT UG od 1 do 2ha = 0,150”).

Next, an attempt to determine the competitiveness level of individual size categories of farms was undertaken based on the monitoring of changes in their mix in years 1950-2009. Within this period, the highest relative growth was noted for the category of farms with the area exceeding 15ha. Hence, this size category was assigned the highest level of competitiveness, i.e. c5 = 1,0000. An increase in the share of very small farms was comparable. Thus, this category was also marked by a relatively high competitiveness. Other competitiveness values set

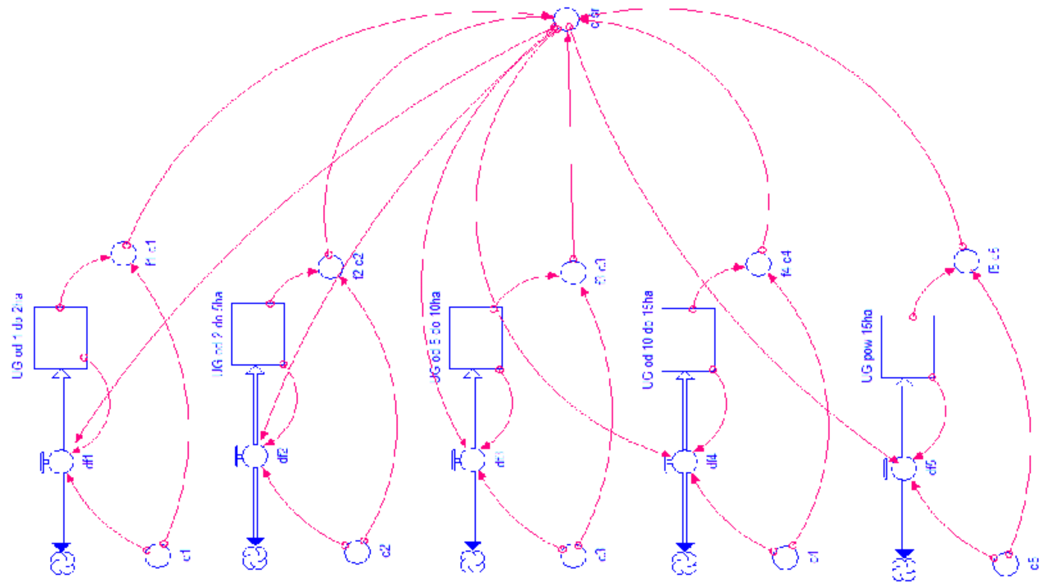

Fig. 2. Flowchart depicting the model of changes in the spatial mix

Source: Authors' own study.

for 2009 and onwards were established so that to ensure that the simulated values resemble the actually noted data. When launching the model making several adjustments, it was established that: c1 = 0,9932; c2 = 0,9860; c3 = 0,9794; and c4 = 0,9890. These values corresponded to a set of equations which define the model. The calibrated model produced the following values in the final year of the simulation:

Despite the fact that a simplified method of model calibration was applied, values arrived at are sufficiently accurate. A comparison of individual competitiveness values provided an interesting study. This relative measurement of benefits (i.e. competitiveness level) enjoyed by the farmer resulting from owning a farm classified in a given size category could now be compared across selected categories. It disclosed the highest values for farms with the area exceeding 15 ha or area lower than 2 ha. The lowest competitiveness values were noted for farms with the area between 5 and 10 ha. Despite the fact that differences between subsequent competitiveness levels do not seem big, their total impact noted over several years in question showed a polarization of subsequent spatial categories of farms.

Systems dynamics models may be successfully applied to forecasting. Taking into account that values produced represent the period of 60 years, the spatial mix simulation was launched for subsequent 40 years, spanning 100 years in total. If we were to adopt a simplified prerequisite which assumes a fixed competitiveness level, it could be concluded that the share of farms with the area between 2 and 10 ha would drop from 71% to 44% by 2050. Moreover, almost 1/3 of the spatial mix of the Polish agriculture would account for tiny farms whereas almost 20% for the largest farms.

Table 2. Spatial mix of agricultural farms in 1950 – start of simulation.

Spatial mix of farms	1-2ha	2-5ha	5-10ha	10-15ha	15ha and above
Actual data	15%	35,9%	35,4%	8,9%	4,8%

Source: Authors' own study.

Table 3. Spatial mix of farms in 2009: end of simulation.

Spatial mix of farms	1-2ha	2-5ha	5-10ha	10-15ha	15ha and above
Forecast	22,1%	34,3%	22,8%	10,2%	10,6%
Actual data	23,4%	33,8%	22,1%	9,4%	11,3%
Forecast approximation error	1,3%	-0,5%	-0,7%	-0,8%	0,7%

Source: Authors' own study.

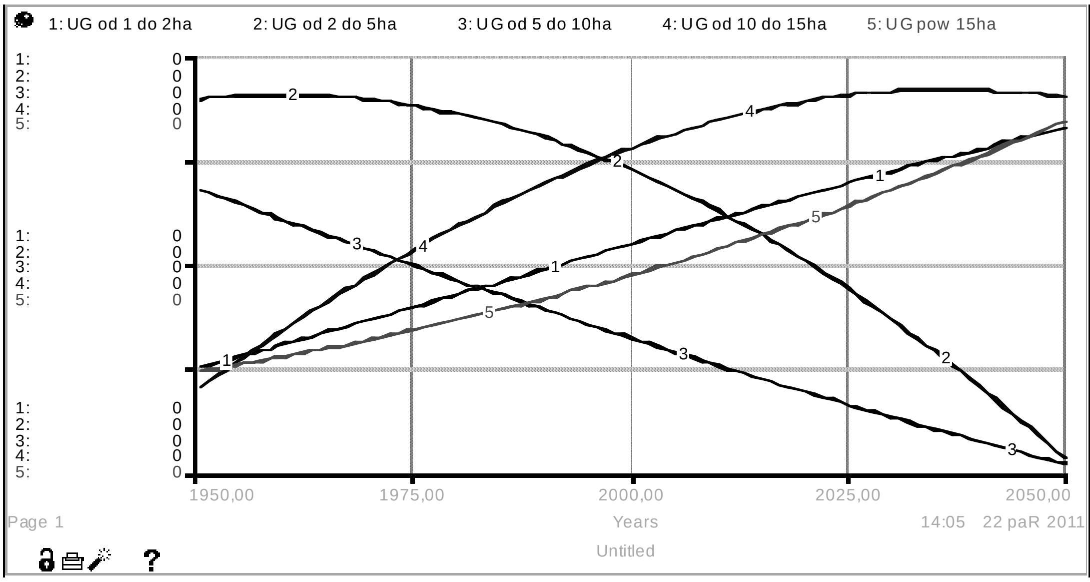

Fig. 3. Simulation of changes in the spatial mix in years 1950-2050
Source: Authors' own study.

Conclusions. Factors which had an impact on agrarian transformations in Poland in the period discussed went far beyond the sphere of agricultural economics. To a large extent, they were linked to the macroeconomic situation, social issues, and the state policy. Under the command and quota system, rational economic calculation had impact on the agrarian structure of the Polish agriculture to a limited extent which was predominantly shaped by doctrinal factors manifested by e.g. the agricultural reform, collectivization, and policy of the authorities of the People's Republic of Poland favoring the cooperative sector, an introduction of compulsory supplies which were set as proportional to the size of the farm, and setting spatial limits. A deteriorating economic condition of the state and an intensified pauperization of the society were also significant factors. Moreover, following a shift in the political system, adverse changes in the agrarian structure were impacted in the initial period of the economic transformation by e.g. an intensified process of farmers' pauperization (in early 1990s, income parity from farming in Poland dropped below 70% of the average income noted nationwide.) KRUS (*Farmers ' Social Security Fund*) regulations are also considered harmful to the agrarian structure. According to numerous experts, they encourage speculations and solidify the smallholder status. This is due to the fact that to become a beneficiary of a low-priced pension and retirement insurance cover, the minimum requirement is to own 1 comparative fiscal hectare of arable land (it is not even necessary to run a farming business.) Land ownership alone has become a sufficient requirement to enjoy the privilege of low-priced benefits. As of Poland's entry into the EU, the Common Agricultural Policy mechanisms have also started to impact the agrarian structure. According to Wilkin (2010), in an adverse manner. Direct payments are an especially important element of the Common Agricultural Policy which has an impact on the agrarian structure. They are granted to farmers who run business operations on at least 1 hectare of arable land and maintain a good culture of the land. Approximately 1.4 million farmers in Poland apply for the payments. The option of using these benefits slows down land trading, hinders the expansion of prospective high-capacity farms, while artificially sustaining very small farm operations which do not disclose any production or produce agricultural goods only to satisfy themselves.

The model presented is a vast simplification of the reality and serves as a start of considerations over the shaping of the agrarian structure of the Polish agriculture. Interpreted as a fixed value, competitiveness of specific spatial categories may undoubtedly fluctuate over time as a result of the applicable agricultural policy. Hence, according to the authors, it would be especially interesting to expand the model by introducing new variables which are closely linked to the current tools of the policy and which could explain how interventionism into agriculture impacts the spatial mix and whether this impact has a positive effect or harms agriculture and consequently contributes to restricting its potential.

Advancing fragmentation provides a threat to the prospects of the Polish agriculture competing with the agricultures of other EU member states. Hence, it is difficult to dismiss approaches which call for an improved agrarian framework as a necessary step. However, it should also be kept in mind that such improvement is usually a very slow and complex process while its pace and characteristics are conditioned by a variety of factors (Instrumenty oddziaBywania PaDstwa…, 2009). Hence, implications of interventions in the agrarian structure should be considered by way of developing models and testing different scenarios; even more so, as history shows that it is much easier to destroy a well-shaped agrarian structure than to restore it.

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УДК 311.2.330.3;33.339.7

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Ключові слова: просторове зрушення, приватне фермерське господарство, економіко-математична модель.

УДК 311.2.330.3;33.339.7

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Ключевые слова: пространственные сдвиги, частное фермерское хозяйство, экономико-математическая модель.

UDC 311.2.330.3;33.339.7

Dacko Mariusz, PhD, **Dacko Aneta,** PhD, **Plonka Aleksandra,** PhD Student**.** Krakow agricultural university. **Kalinichenko Antonina Volodimirivna,** Dr hab, prof. **Malynska Lidiya Volodimirivna.** Poltava state agricultural academy. **Economical-mathematical model of changes in spatial mix of private farms in Poland.** In the article questions of a current state and a problem of agrarian sphere in Poland are taken up. This study discusses the dynamic model used to strive and explain the change process noted in the spatial mix of private agricultural farms across Poland over the last 60 years. Based on the model, levels of competitiveness of specific spatial categories of farms are estimated and an answer to the following question is sought: 'How may the spatial mix of the Polish agriculture change in the future?'

Keywords: spatial mix, private farming / agriculture, economical-mathematical model.

Стаття отримана редакцією 17.01.2012 р.